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Calculation of Inter-Room Air Movement for Multi-Room Building Energy Analysis

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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CALCULATION OF INTER-ROOM AIR MOVEMENT FOR MULTI-ROOM BUILDING ENERGY ANALYSIS

George N. Walton

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National Bureau of Standards
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Washington, DC 20234

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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ABSTRACT

A model is presented for computing the infiltration and air flow between rooms of a multi-room building in terms of basic principles of fluid mechanics. This model has been incorporated into a comprehensive loads-predicting computer program. Air flows, room temperatures, and heating loads for a typical townhouse under different conditions of environment and with various construction features are computed. These calculations show the feasibility of detailed multi-room air movement analysis. They also indicate that when the inter-room openings of a low-rise structure are large compared to the envelope openings, the infiltration and total load can be accurately, and more quickly, computed by assumming no resistance to air flow between rooms. This property will also allow simplified calculations for high-rise buildings with many rooms. Methods are proposed for handling more complex air flow phenomena.

Keywords: building energy analysis; computer simulation; infiltration; natural ventilation.

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1. INTRODUCTION

1.1 BACKGROUND

The effort to encourage the design, construction, and retrofit of energy conserving buildings will be strengthened by the development of comprehensive methods of evaluating the thermal effectiveness of those buildings. Algorithms which can accurately determine heat flow quantities, especially for natural heating and cooling applications, are not presently included in existing energy analysis computer programs and must be developed and tested over a wide range of parameters before they can be adapted into standard user-oriented design tools. Among these design tools are the BLAST [1] and DOE-2 [2] programs. These programs include simulation of operational and physical characteristics for many building features which allows the study of the interactions of design options. Although these programs are extremely versatile and efficient for conventional buildings and for conventional operating procedures, they lack feasibility in analyzing innovative building designs. Moreover, they are difficult to modify for the testing of new algorithms. One of the major areas neglected in DOE-2 and BLAST is the energy transfer due to air movement. This includes both the effects of building construction on infiltration, natural ventilation, and inter-room air movements in passively heated and cooled buildings.

A research-oriented program is needed to allow the detailed study of simultaneous air, heat, and moisture transfer in and through a building with complex internal architecture. A research program must be easily expandable to test the simulation of new features. This requirement implies that the program should have a simple structure and be well documented. The program should also be able to handle small or very large problems and be portable so it can be used by many researchers.

1.2 OBJECTIVES

The primary objective of this effort is to develop a research-oriented building loads analysis computer program. This program should include the best available algorithms for multi-room analysis of heat and air transfer. It must also include a sufficient variety of building feature models to allow parametric studies of the interactions of any proposed algorithms with the many complex features present in real buildings.

---

[1] Hittle, D.C., The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0: Users Manual, U.S. Army Construction Engineering Research Laboratory Report TR-E-153, June 1979.

[2] DOE-2 Users Guide, Version 2.1, Lawrence Berkeley Laboratory Report LBL-8698, May 1980.

1.3 SCOPE

The present version of this research program developed in the Environmental Analysis Group of the National Bureau of Standards is called the Multi-Room Loads Program (MRLP). It is the first phase in the development of a general research program. It is based on the BLAST program which uses a very detailed room heat balance technique. The MRLP adds to that technique an algorithm for computing infiltration and inter-room air movements for arbitrarily complex geometry. The MRLP uses a new input language, a revised program structure, and is written in standard FORTRAN 77 to create a modifiable program. This report gives an overview of the MRLP and a detailed discussion of the air movement algorithm (section 2). The preliminary results of sample calculations are discussed (section 3). The limitations of the proposed algorithm and opportunities for improved efficiency and other areas for further development are discussed at the end of section 3. Detailed documentation of the MRLP is in preparation.

2. METHODS

2.1 SIMULATION CAPABILITIES

The Multi-Room Loads Program uses detailed heat balance techniques to compute room loads, as described below in section 2.2. The program uses a one-hour time step. Transient features are modeled by a quasi-steady-state analysis except for thermal conduction. The MRLP may be used to evaluate single "design" days or use up to one year of measured weather data. A large number of occupant usage features may be scheduled with hourly, daily, and seasonal variations. The effects of temperature drifts in response to various control strategies can be accurately evaluated. Other capabilities can be grouped by the three modes of heat transfer.

Conduction: Transient conduction effects are modeled by "conduction transfer functions," which are extensions of response factors. They model the heat storage effects of walls, furnishings, and partitions between rooms. Movable insulation is closely approximated by a massless insulation model with appropriate controls. This movable insulation may be applied over windows or walls.

Radiation: The transmittance and absorptance of windows is computed from the optical properties of the window panes. There may be up to four panes which may be heat absorbing or have reflective films. Shading coefficients may be used for windows which cannot be described in terms of their components. The shadowing and distribution of sunlight on surfaces may be calculated in several levels of detail up to the amount of light transmitted through windows onto each surface of the room. The effects of "non-black" interior and exterior surfaces can be modeled. There is a simple model to account for the energy savings of daylighting.

Convection: The program uses variable interior and exterior convection coefficients. It can compute infiltration and the natural flow of air between rooms caused by wind and thermal forces. There is an alternative simple model for infiltration with options of ventilation cooling, a whole house fan, and controlled air mixing between two rooms.

The program structure is described in appendix A and the input in appendix B.

2.2 ROOM ENERGY BALANCE

The calculation of the room air temperature is based on a heat balance on the room air. The convective gains from the room surfaces and internal sources plus the sensible gains from incoming air plus the energy added by the air handling system must equal zero.

$$CE + \Sigma\ HC_j * A_j * (T_j - TZ) + \Sigma\ F_i Cp * (TS_i - TZ) + L = 0 \qquad (1)$$

where

CE = energy convected from internal sources
A_j = area of surface j

HC_j = convection coefficient of surface j
T_j = temperature of surface j
TZ = room air temperature
F_i = mass flow of air through opening i
Cp = specific heat of air
TS_i = temperature of the air through opening i
L = energy from the air handling system

The summations apply to all surfaces/openings which are part of the room. The values of the surface temperatures T_j, are obtained by evaluating a heat balance at every suface of the room using an assumed room temperature. A better estimate of the room temperature is then obtained by solving equation 1 for TZ. Repeating this process leads to successively better approximations of the surface and air temperatures. The process is rapidly convergent. Multiple rooms can be handled within the iterative scheme given an appropriate data structure and proper heat balances on the surfaces between rooms. Details of the surface heat balances are beyond the scope of this report. They are essentially the same as those implemented in BLAST, version 3.0. The remainder of this report will discuss the method for computing the air flows through envelope and inter-room openings.

2.3 NATURAL AIR MOVEMENTS

Most building surfaces contain openings, either large or small, which permit the movement of air through them whenever there is a pressure difference across the surface. Pressure differences arise from naturally occurring wind and thermal forces. The following discussion of air movements emphasizes the relationships to basic principles of fluid mechanics.

2.3.1 Wind Forces

Wind pressures on surfaces are proportional to the velocity head of the undistributed air stream [3]. The wind pressure (PW_i) is thus calculated from Bernoulli's equation as

$$PW_i' = 0.5 * D_a * V**2 \quad (2)$$

The density of air is related to the barometric pressure (PB) and air temperature (Ta) by

$$D_a = 0.0034838 * PB/(T_a + 273.15) \quad (3)$$

Wind speed (V) increases with height according to the formula

$$V = V_o * b * (Z/Z_o)**a \quad (4)$$

---

[3] ASHRAE Handbook 1977 Fundamentals, p. 21.1.

where

V_o = wind speed at standard conditions
Z = height being considered
Z_o = standard height of wind measurements (10 m)
a,b = terrain-dependent coefficients given below.

Terrain Parameters for Standard Terrain Classes [4]

Class	Description	a	b
1	Ocean or other body of water with at least 5 km of unrestricted expanse	0.10	1.30
2	Flat terrain with some isolated obstacles (buildings or trees well separated from each other)	0.15	1.00
3	Rural areas with low buildings, trees, etc.	0.20	0.85
4	Urban, industrial, or forest area	0.25	0.67
5	Center of large city (Manhattan)	0.35	0.47

The wind speed is evaluated at the highest point of the surface.

Wind direction effects are dependent on the building's configuration and its relationship to surrounding structures. No single correlation can truly model directional effects on all buildings or even the effects on a single building in different environments. The following correlation is a compromise derived by averaging several published correlations. It accounts for the trends observed in wind pressure measurements [5, 6].

Let Y = angle of incidence of wind on the surface (0<=Y<=180.)

$$\text{If}(Y<=90.)\ PW_i = (.75-1.05*Y/90.) * PW_i' \quad (5a)$$
$$\text{If}(Y>=90.)\ PW_i = (0.15*Y/90.-.45) * PW_i' \quad (5b)$$

---

[4] Sherman, M.H. and D.T. Grimsrud, "Infiltration-Pressurization Correlation: Simplified Physical Modeling," ASHRAE Transactions, Vol. 86, Part 2, 1980.

[5] Shaw, C.Y. and G.T. Tamura, "The Calculation of Air Infiltration Rates Caused by Wind and Stack Action for Tall Buildings," ASHRAE Transactions, Vol. 83, Part 2, 1977.

[6] Shaw, C.Y., "A Method for Predicting Infiltration Rates for a Tall Building Surrounded by Lower Structures of Uniform Height," ASHRAE Transactions, Vol. 85, Part 1, 1979.

2.3.2 Thermal Forces

Temperature differences cause air density differences which produce bouyancy (or stack) effects. The magnitude of the force on a submerged surface (all surfaces are submerged in air) is equal to the area times the pressure at the centroid of the area. It is therefore necessary to know the pressure at the centroids and the locations of those centroids. The effects of air density on the pressure on any surface can be considered by a single simple formula. The pressure at height Z_1 is equal to the pressure at height Z_2 plus fluid density times the gravitational constant times $(Z_2 - Z_1)$. Figure 1 shows a surface separating two vertically adjacent rooms. The pressure differences (ΔP) across the surface is $P_j - P_i$. It is more useful to know this ΔP in terms of P_m and P_n which are the reference pressures of rooms n and m.

$$P_j = P_m + D_m * g * (Z_m - Z_j) \tag{6a}$$

$$P_i = P_n + D_n * g * (Z_n - Z_i) \tag{6b}$$

The same formulae apply to a vertical surface as in figure 2. They also apply to an envelope surface where P_j is the pressure of the outside air (figure 3). Ambient air variables are substituted for the room m variables:

$$P_j = P_a + D_a * g * (Z_a - Z_j) \tag{6c}$$

Z_a is the reference height for air pressure measurements. Its location is arbitrary. The room reference height, Z_n and Z_m, are also arbitrary. All are chosen for convenient or physically meaningful representation. The absolute values for the room pressures (P_n, P_m) and the air pressure (P_a) are also arbitrary since only pressure differences cause air flow.

The pressure difference across surface i is

$$\begin{aligned} \Delta P &= P_j - P_i \\ &= P_m - P_n + D_m*g*(Z_m-Z_j) - D_n*g*(Z_n-Z_i) \\ &= P_m - P_n + PS_i \end{aligned} \tag{7}$$

where

$$PS_i = D_m*g*(Z_m-Z_j) - Dn*g*(Z_n-Z_i)$$

and is the "stack pressure" on surface i.

The height of the centroid of a triangle or rectangle is the average of the heights of the vertices. Since the stack effect also occurs within the thickness of a horizontal surface and since it is necessary to leave no building internal height unaccounted, Z_i and Z_j in figure 1 should both be replaced by their average.

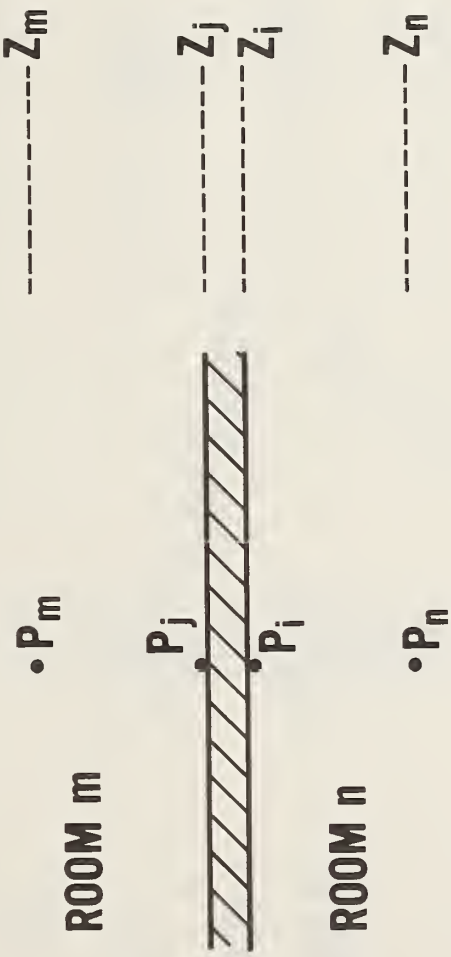

Figure 1. Vertically adjacent rooms

Figure 2. Horizontally adjacent rooms

Figure 3. Envelope surface

2.3.3 Flow Equations

The flow through small openings in a surface is based on the orifice equation

$$F = C * A * D * \sqrt{2 * \Delta P/D} \qquad (8)$$

where A is the observed opening area and where the flow coefficient, C, is a function of the Reynolds number and the ratio of the opening size to the entire surface. When the opening is small, C equals 0.6 for a wide range of Reynolds numbers [7]. The MRLP assumes this value of C. The user may modify c by using an effective flow area (FA) which differs from the actual opening area. Experimental results indicate that flow through real surfaces is a combination of orifice flow ($F \propto \sqrt{\Delta P}$) and capillary flow ($F \propto \Delta P$) with an exponent of about 0.65 [8]. In order to retain the concept of opening area and provide a simple grouping of all other terms in equation 8, C is multiplied by $\sqrt{2}$ and D divided by $\sqrt{D}$ to give:

$$F_i = 0.848 * FA_i * \sqrt{D} * \Delta P^{**}X_i \qquad (9)$$

where FA_i is the effective flow area of the openings in the surface and D is the density of incoming air. The pressure difference for envelope surfaces is

$$\Delta P = PW_i + PS_i - P_n \qquad (10a)$$

and the ΔP for inter-room surfaces is

$$\Delta P = PS_i + P_m - P_n \qquad (10b)$$

The surface flow equation becomes

$$F_i = 0.848 * FA_i * \sqrt{D_m} * \Delta P^{**}X_i \qquad (\Delta P > 0) \qquad (11a)$$

or

$$F_i = -.848 * FA_i * \sqrt{D_n} * (-\Delta P)^{**}X_i \qquad (\Delta P < 0). \qquad (11b)$$

For each room there must be a mass balance

$$F_s + \Sigma F_i = 0 \qquad (12)$$

where F_s is the net mass flow into the room from the air-handling system. These mass balances form a system of non-linear algebraic equations which can be solved for the room pressures.

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[7] ASHRAE Handbook 1977 Fundamentals, p 4.10.

[8] ASHRAE Handbook 1977 Fundamentals, p .21.4.

2.3.4 Solution of the Flow Equations

There are several methods for solving such a set of equations. Most involve computing the following partial derivatives:

$$\frac{\partial F_i}{\partial P_n} = -X_i * F_i/\Delta P \tag{13a}$$

$$\frac{\partial F_i}{\partial P_m} = X_i * F_i/\Delta P \qquad \text{(inter-room surface)} \tag{13b}$$

or

$$\frac{\partial F_i}{\partial P_m} = 0 \qquad \text{(envelope surface)} \tag{13c}$$

Note that it is not necessary to evaluate $\Delta P^{**}(X_i-1)$ to compute these derivatives. The simplicity of the derivative calculation indicates that methods which approximate the derivative are not necessary. Note also that as ΔP approaches zero these derivatives cannot be evaluated. This condition applies for large openings which cannot support a large pressure difference (except with very high flow rates). This a potential source of trouble which must be considered.

Two methods for solving the air flow equations were studied. First was the standard Newton's method for systems of equations [9]. This method was found to give fast solutions in several test cases but to be non-convergent in other very similar cases. Convergence could be obtained in those cases by the choice of a suitable relaxation coefficient. The tests showed no pattern of non-convergence which would allow prediction of a usable relaxation coefficient.

The second method tested was a simple iterative scheme from Conte and De Boor [10]. It called for successively approximating each zone pressure according to

$$P_n^{(k+1)} = P_n^{(k)} - \Sigma\, F_i/\Sigma \frac{\partial F_i}{\partial P_n} \tag{14}$$

where k is the iteration number. This method was often slower than Newton's method, but it converged for all of the simple test cases. It was therefore chosen for use in the MRLP.

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[9] Stoecker, W. F., Design of Thermal Systems, McGraw-Hill, 1971, pp. 92-93.

[10] Conte, S.D. and De Boor, C., Elementary Numerical Analysis, an Algorithmic Approach, McGraw-Hill, 1972, p. 88.

2.4 SAMPLE PROBLEM

A study of the combined multi-room heat balance with air flow simulation was done by using a "typical design" townhouse [11]. The floor plan is shown in figure 4, and figure 5 is a section of the townhouse. There is a total of (1315 ft^2) 122 m^2 living area on the two levels and (10850 ft^3) 307 m^3 of conditioned space.

The MRLP input deck describing this building is given in appendix C. The building is divided into 5 thermal zones: the first floor and stairwell (room 1), each of the three bedrooms (rooms 2, 3, and 4), and the attic (room 5). Conductive heat transfer was modeled with 98 surfaces, and air flows were modeled in 37 openings. The model probably uses much more detail than is necessary to obtain a reasonable estimate of the energy requirements, but the detail is useful in testing the capabilities of the program.

The opening areas were assumed according to ASHRAE [12] which suggests openings of about .02 percent to .05 percent of the total surface area for frame walls and .01 percent to .04 percent for ceilings. The largest values were chosen for the test building. Inter-room partitions and floors were also given .05 percent openings. Additional inter-room opening areas of 0.046 m^2 (0.5 ft^2) for the (almost closed) doors were used in the base case. The attic had a soffit area of 0.186 m^2 (2.0 ft^2) on the north side only and a porosity of .10 percent for the roof.

---

[11] Hastings, S.R., "Three Proposed Typical House Designs for Energy Conservation Research," National Bureau of Standards Interagency Report (NBSIR) 77-1309, 1977.

[12] ASHRAE Handbook 1977 Fundamentals, p. 21.7.

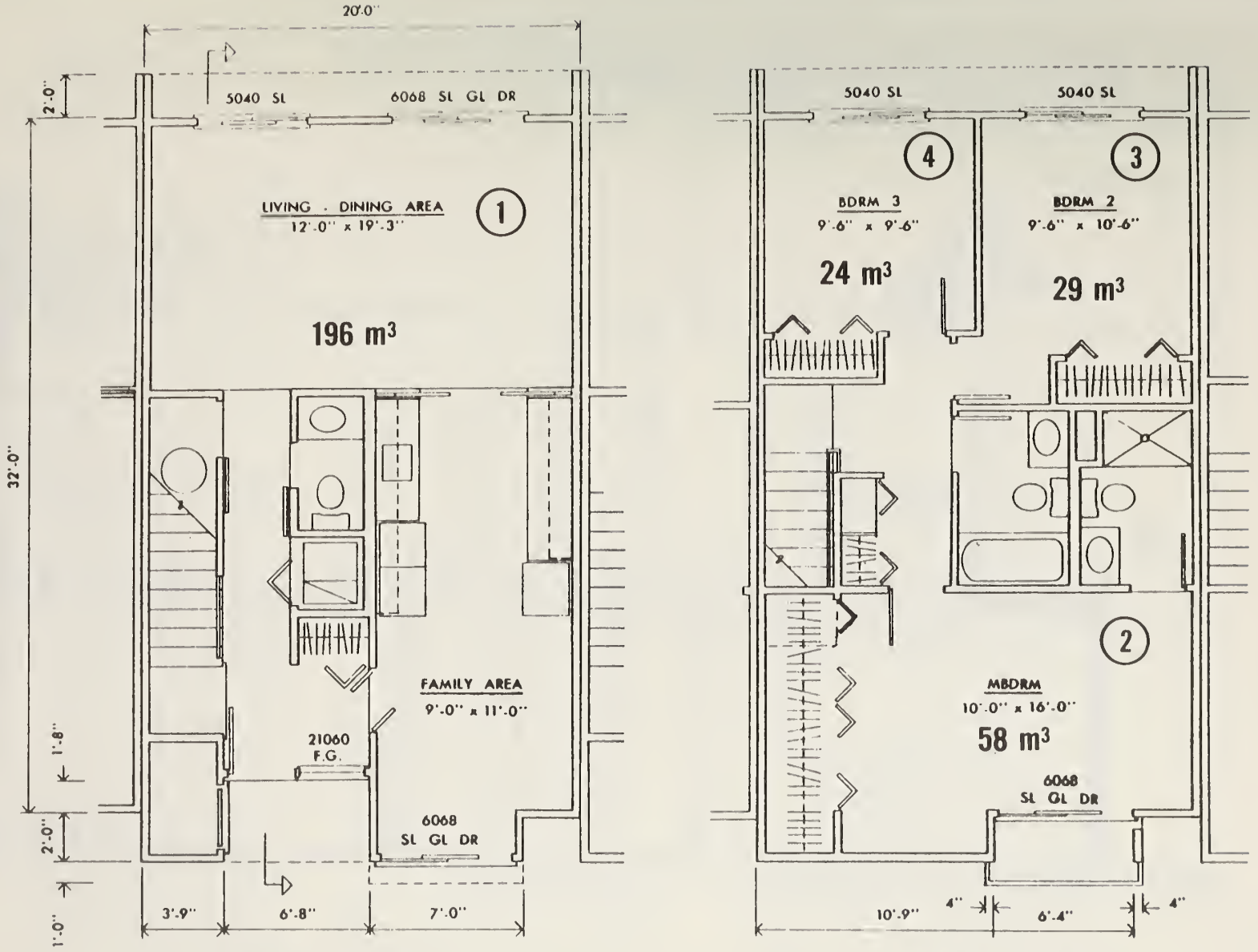

Figure 4. Townhouse floor plan

Total volume - 307 m³ (10,840 ft³)

Total area - 122 m² (1315 ft²)

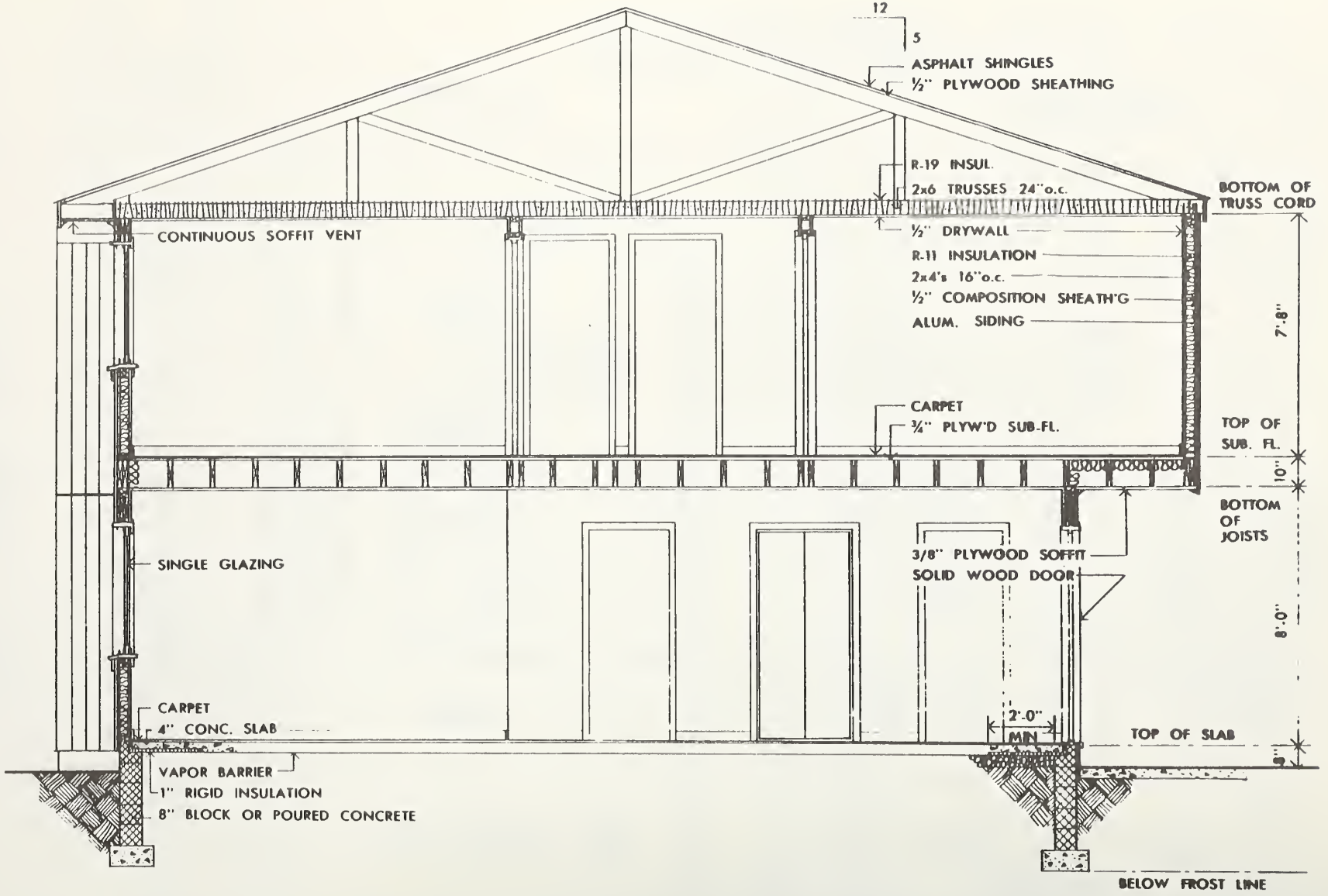

Figure 5. Section of townhouse

3. RESULTS AND DISCUSSION

3.1 WIND DIRECTION EFFECTS

Figure 6 shows the results of three test computer runs for a winter weather condition with only the wind direction changed. When the wind blew perpendicular to the exposed sides of the house (cases 6a and 6c), an infiltration rate of just over one air change per hour (ach) was produced. The location of the soffit is the primary reason for the difference in results between the cases of north and south winds. When the wind blew parallel to the townhouse (case 6b), infiltration was only .22 ach. This was due mostly to stack effect. These values compare favorably to ASHRAE design air change rates for residences [13]. ASHRAE recommends 1 ach for rooms with windows or exterior doors on one side and 1.5 ach for rooms with windows or exterior doors on two side. For rooms with weatherstripped windows or with storm sash, two thirds of these values should be used. The estimated loads (case a = 7.41 kW, case b = 4.68 kW, case c = 7.87 kW) show that infiltration and wind direction effects on infiltration are important components of total heating load of this typical structure. Computation times varied from about 7 to 15 seconds per simulation day.

3.2 INTER-ROOM OPENINGS

Figure 7 shows four cases comparing the effects of the size of inter-room openings on the air change rates, loads, and calculation times. The small openings simulation (case 7a) assumes 0.009 m^2 (0.1 ft^2) openings between rooms instead of the standard 0.046 m^2 (0.5 ft^2) (case 7b) openings. The third case (7c) simulated infinite openings between rooms by modeling the four rooms of the townhouse as a single room. There is no significant change in the calculated loads in these three cases (7.34 kW, 7.41 kW, and 7.42 kW) which go from the smallest reasonable inter-room openings to no inter-room flow resistance. Although the total load in the small openings case is only one percent smaller than the base case, there are much greater differences in the loads of the individual rooms (room 1 = +1 percent, room 2 = +6 percent, room 3 = -8 percent, room 4 = -8 percent). This is noticeable in real buildings where closed-off rooms on the windward side become colder than the leeward rooms.

The fourth case (7d) used the air change rate computed for the single room model to compute loads based on a known air change rate instead of on the pressure and air flow balance model. This gave the same load, as it should, and required only 3.9 seconds/day simulation time. The time of other cases in excess of this amount is the computation cost of the detailed air flow algorithm. These calculation times are good only for relative comparsions because they are greatly affected by the numbers of surfaces, rooms, and openings and the convergence limits of the simulation. Comparing case 7c to 7d, the increase in computation time of 18 percent appears justified because of the importance of infiltration in the total heating load of the building. However, in case 6b infiltration is making a much smaller contribution to the load and calculation

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[13] ASHRAE Handbook 1977 Fundamentals, p. 21.5, table 1.

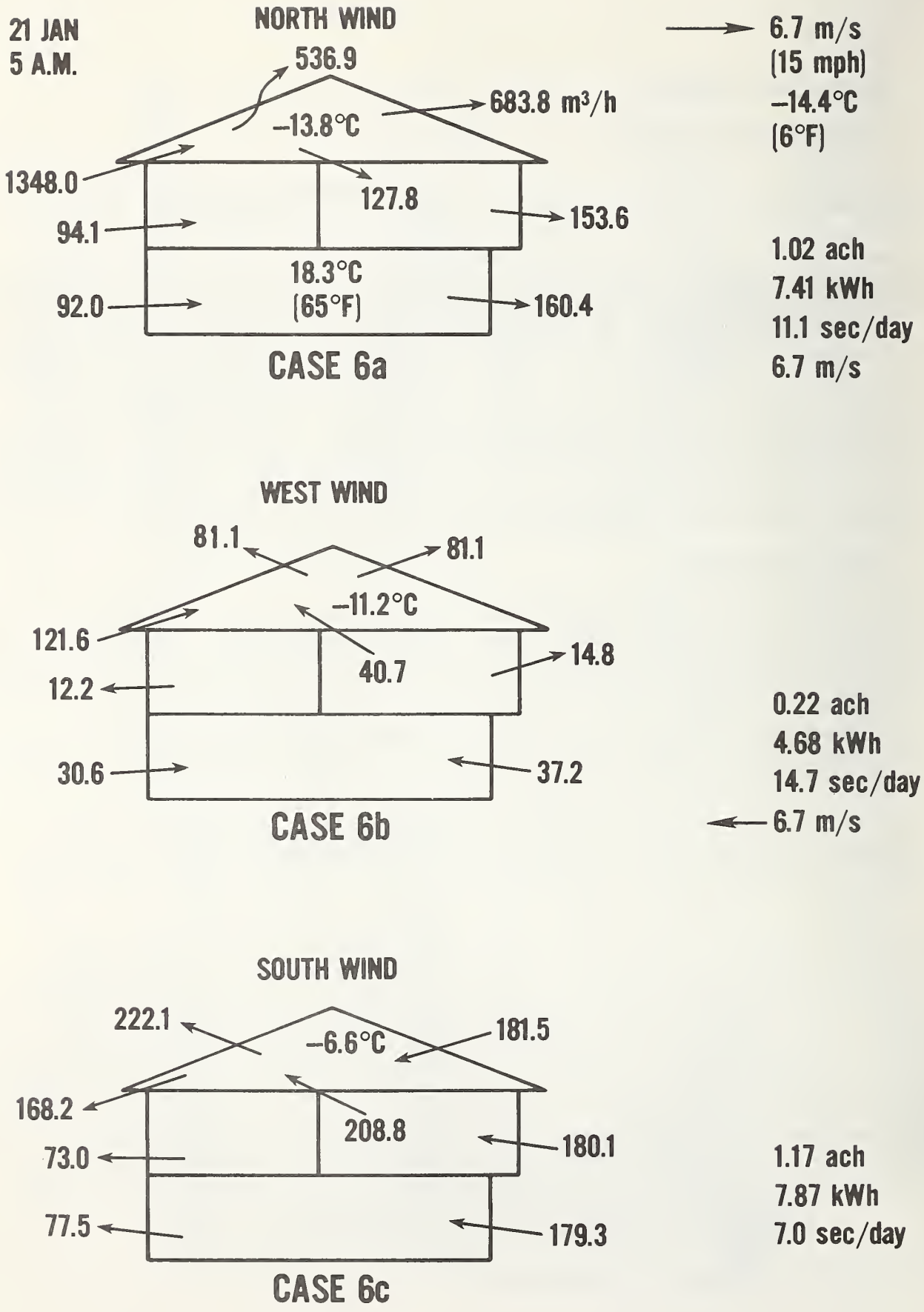
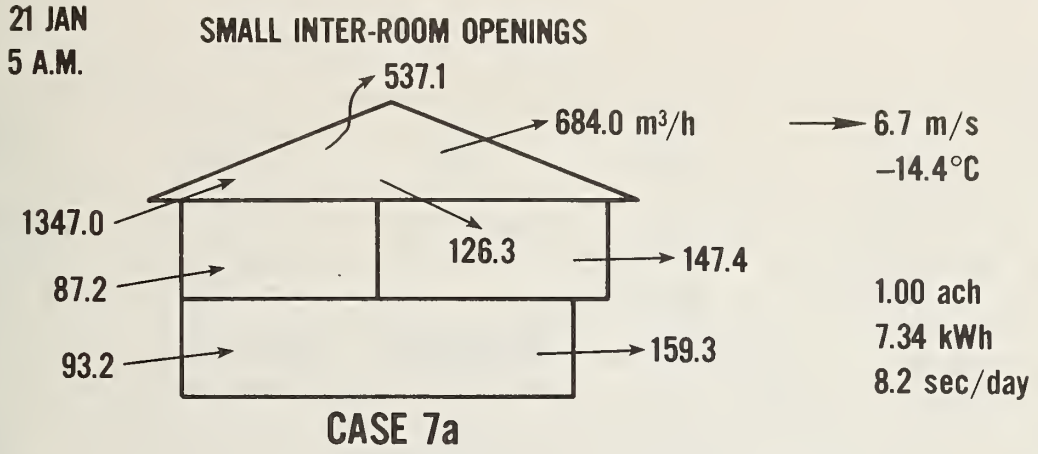
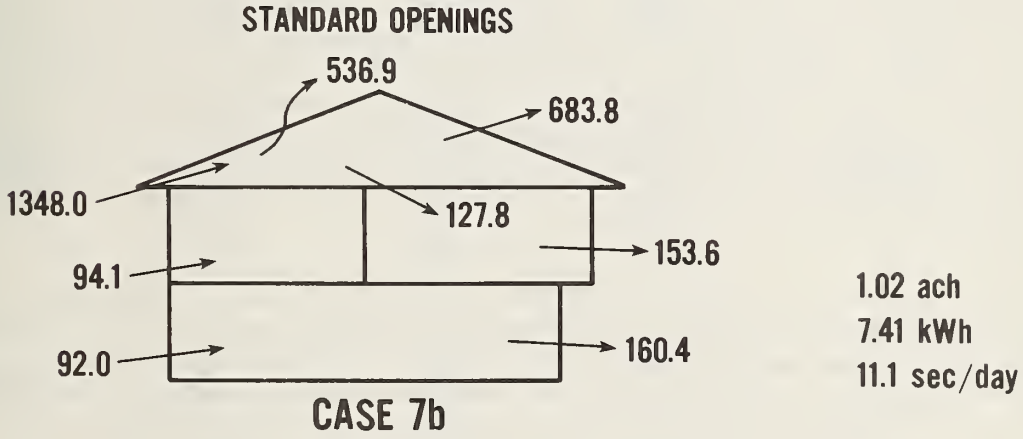
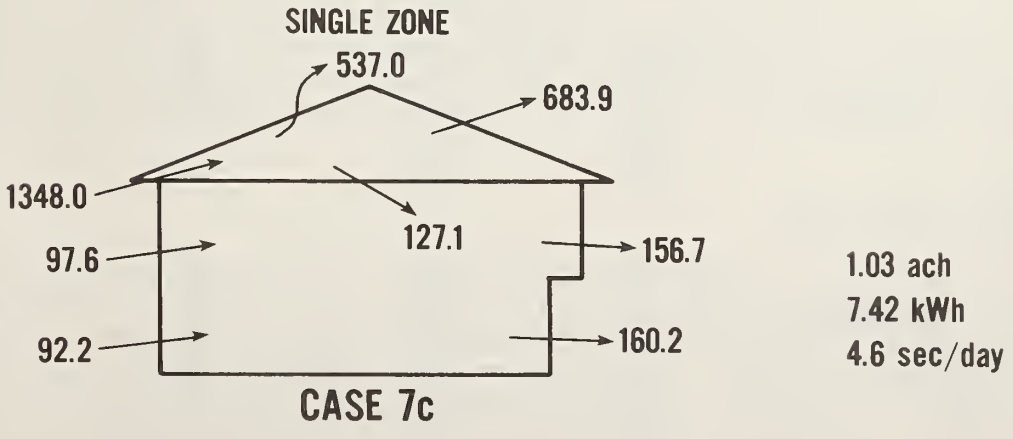


Figure 6. Wind effects - computer air flows through major building surfaces







CASE 7d

AIR CHANGE METHOD: using same ach gives same load 3.9 sec/day

Figure 7. Inter-room openings

time is almost 15 seconds. In this situation the computational cost is not justified.

Note in the multi-room cases that as the areas of the inter-room openings increase, the calculation time goes up dramatically. In fact, it was not possible to simulate a case with 0.186 m^2 (2.0 ft^2) openings between rooms. This situation called for the development of a simple test case to study the effects of inter-room opening area on the calculation technique. The results are shown in figure 8. The first case represents a single room consisting of two walls, each with opening areas of 0.01 m^2 (0.11 ft^2) one facing into a 6.7 m/s (15 mph) wind and one facing away from it. The flow through the room is computed to be 2.98 m^3/h (105. ft^3/h) and requires only 2 iterations. The next case shows the original room divided into two rooms by a partition containing a 0.01 m^2 opening. This reduces the air flow rate to 1.95 m^3/h (68.9 ft^3/h) and raises calculation time to only 3 iterations. As the area in the partition opening is doubled in succeeding cases, the air flow rate approaches the single room flow rate while the calculation time increases rapidly. For example, the partition with 0.08 m^2 opening area has a flow within one percent of the single room value but requires over twelve times as long to calculate. The next larger case, 0.16 m^2, could not be calculated within the iteration limit. However, it is obvious that assuming the single room air flow value would be correct to within one percent.

This situation may be considered a problem or an opportunity. Doorways, ductwork, and the lack of vapor barriers cause interior partitions to have much larger flow areas than exterior walls in typical low-rise construction. If those openings are to be modeled exactly, another algorithm must be developed to solve the air flow equations. On the other hand, the small effect that large inter-room openings have on the infiltration and the loads indicates that it may be possible to separate the problem. Infiltration could be computed by assuming that relatively large inter-room openings are effectively infinite. Then the inter-room flows would be computed based on the net infiltration into each room. High-rise buildings are usually constructed to have relatively small openings between floors to reduce the stack effect, but all the rooms on a single floor are usually well coupled. Therefore, some separation should still be possible.

3.3 NATURAL VENTILATION

Other tests of the two-room model indicated that it is the relative size of the inter-room and envelope openings, not the absolute size, which is affecting computation time. Solutions were reached rapidly for all cases where the envelope openings were larger than the partition openings. This property permitted modeling the soffit of 0.186 m^2 (2.0 ft^2) with no problems. It suggested that it should be possible to simulate the condition where the envelope openings are about the same size as the inter-room openings. This is the case when windows have been opened to get natural ventilation. Figure 9 shows how ventilation can affect the building conditions. A warm, sunny fall afternoon was chosen as the test weather condition. The top figure (case 9a) shows the air flow rates and room temperatures for the standard configuration of envelope and partition openings. Note that the south bedroom is at 35.8 C (96.4 F). In

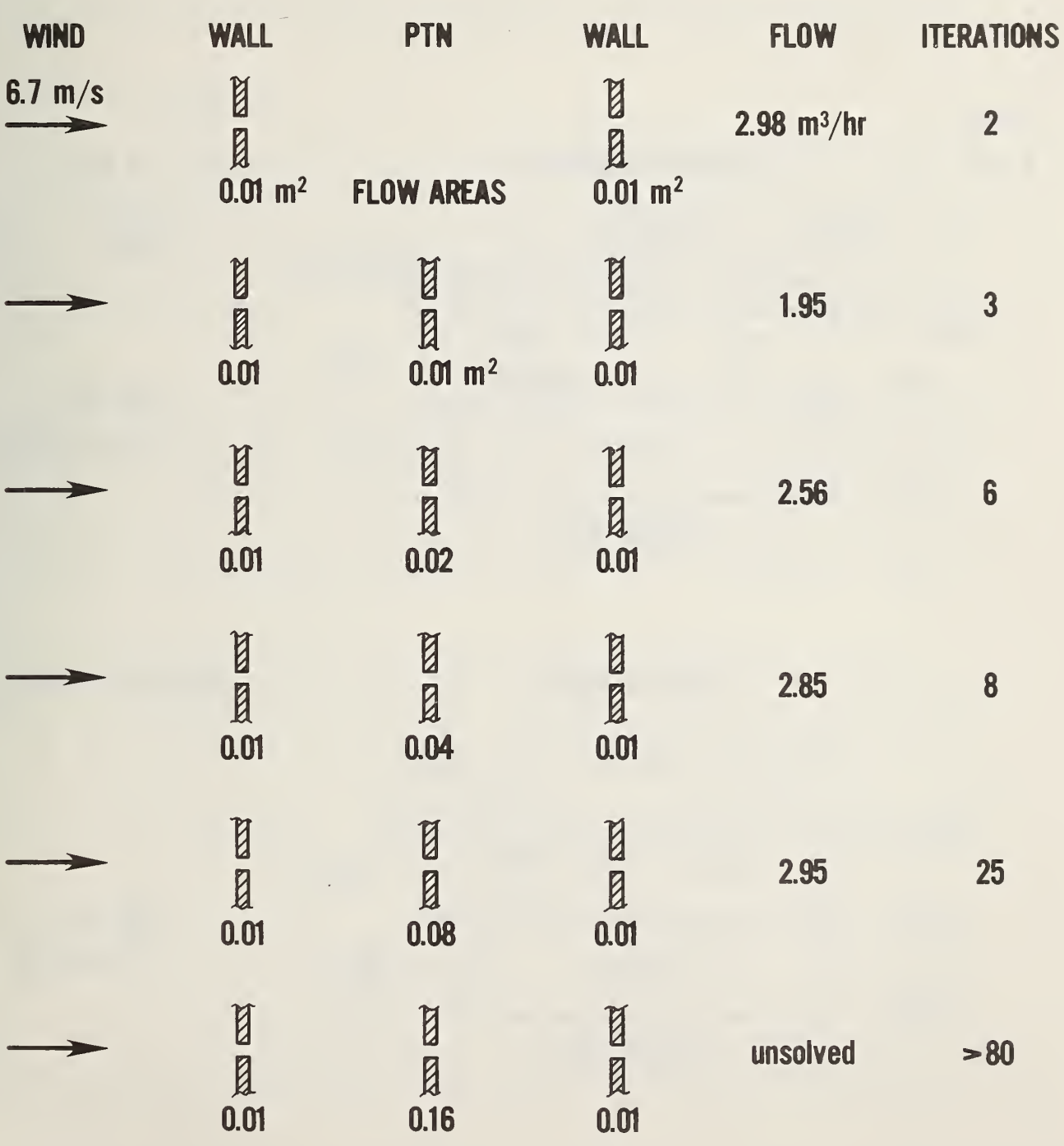


Figure 8. Effect of interior partition

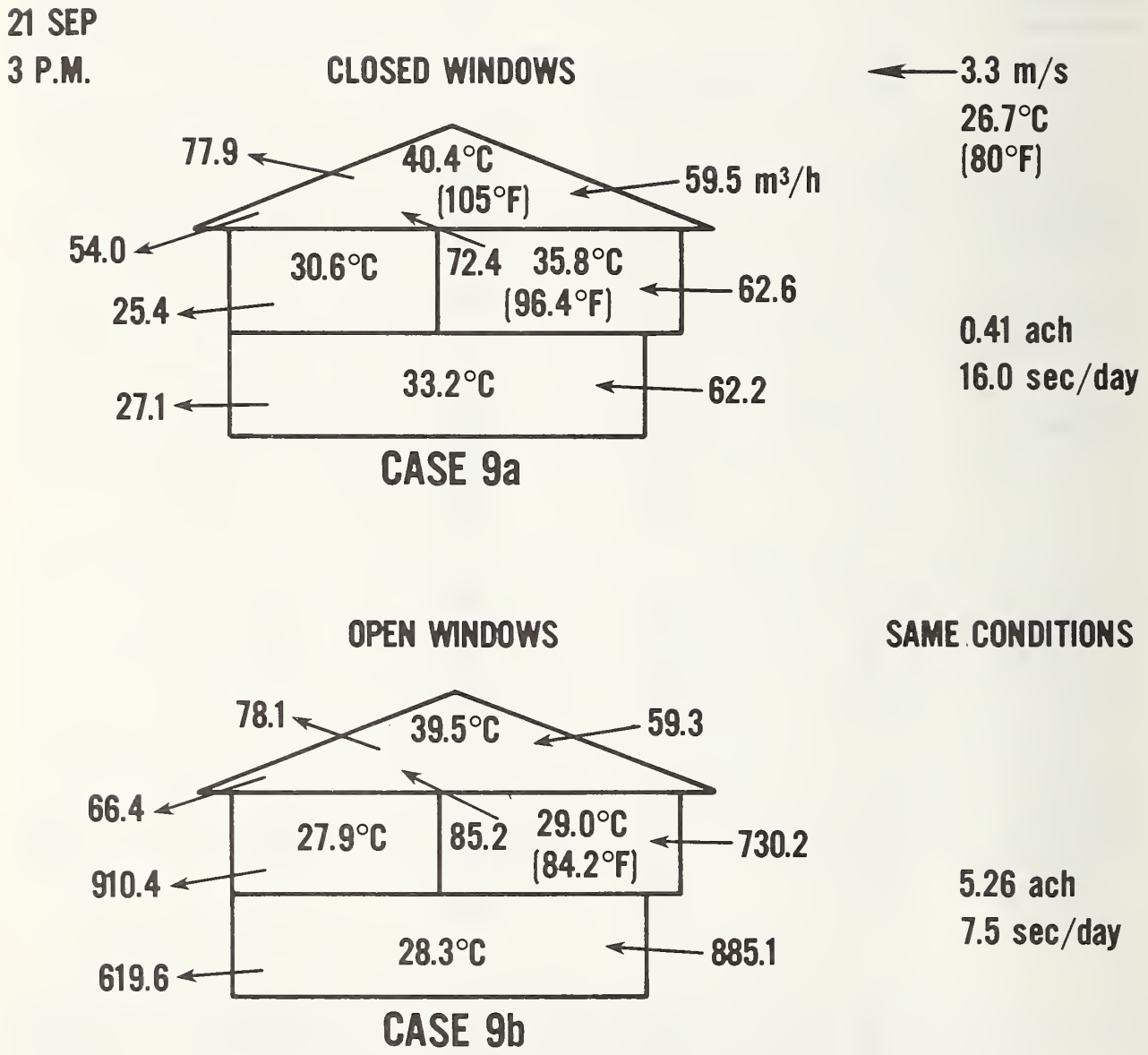


Figure 9. Natural ventilation

case 9b windows and inter-room doors have all been opened to 0.186 m^2 (2.0 ft^2). This produces greater than 5 ach and reduces the south bedroom temperature to 29 C (84.2 F).

3.4 FUTURE DEVELOPMENTS

The MRLP air movement algorithm is theoretically capable of modeling high and low openings in a single wall. This was not tested in the sample problem. It has potential use in the case where one room is significantly hotter than the other and a stack effect is developed between the high and low openings. This condition occurs in a Trombe wall where the space between the cover and the wall may be considered and extremely narrow room. The narrowness of the room adds a further resistance to air flow (besides that of the wall openings) which should be added to the air flow model.

The air flow model does not address two important classes of openings. One is the doorway where bi-directional flows can occur. It may be possible to handle this by using a high and a low opening. The other case is the opening between floors as it is affected by thermal stratification. A very rapid air exchange will take place between a warm room below a cold room, whereas almost no air will move between a cold room below a warm one. This diode effect will add a further complication to the already non-linear air flow equations. Two openings may set up a large convection pattern with much greater air movement than a single opening of equivalent area.

The possibility of separating the envelope from the inter-room air flow calculation suggests a way of handling these additional features. ASHRAE [14] shows that the flow through an orifice is no longer proportional to the square root of ΔP at very low Reynolds number. In fact, it becomes proportional to ΔP. The Reynolds number of air flow between rooms connected by an open door appears to be typically in a transition region. If it can be modeled to sufficient accuracy by the linear assumption, solution of the multi-room flow problem would be greatly simplified. Only simultaneous linear equations would have to be solved. It may also be possible to superimpose bi-directional effects.

The general problem of thermal stratification in the room air should also be addressed. Two simple models are possible. The first would assume a linear temperature profile from the room's coldest point at the floor to its warmest point at the ceiling. The slope of this profile would be determined experimentally. The second method would divide the room air into two parts: a warm upper layer and a cooler bottom layer. Energy would be convected between these layers and from walls and internal sources to each layer according to experimentally determined coefficients. Heat balances could then be performed for each layer.

The current air flow model and the possible extensions all require experimental validation to show if they are sufficiently accurate. If it is also shown that the computation cost is low enough, the method can be recommended for use in

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[14] ASHRAE Handbook 1977 Fundamentals, p 4.10.

energy analysis design tools. It would then be necessary to develop a data base of openings areas and flow exponents for different building constructions for design use.

APPENDIX A: PROGRAM STRUCTURE

The program is written almost entirely in FORTRAN 77. This is a standard language which has been or is being implemented on most large and medium size computers. The handling of character data and direct access files help to make this language machine-independent. The MRLP should be portable except for some conversions from single to double precision and replacing the use of BLAST weather tapes. The PARAMETER feature of FORTRAN 77 is used extensively in modifiable array dimensions so the MRLP can handle different size problems.

The MRLP is divided into two subprograms: the input processor (IP) and the loads calculator (LC). This structure is illustrated in figure A1. The IP checks the user input, prepares input files for the LC, and reports the array sizes that the LC will require. The LC performs the building loads simulation and reports the results. This separation of subprograms allows a reduction in computer core requirements. The IP uses minimal array sizes because it processes the input one element (surface, schedule, material, etc.) at a time. The LC uses large arrays which consider these elements simultaneously. The LP and LC may be run as separate jobs when it is necessary to recompile the LC for correct array sizes, or they may be run as a single job if the LC is known to have sufficiently large arrays.

The input processor is divided into four major sections. These correspond to the input language sections which they process. This sectioning allows further reductions in core requirements by the use of overlays (or segments). A small input processor is important to allow the fast job turn-around necessary to quickly debug the user input deck. Each section contains several subroutines which process the input language "keys" plus others for special elements of certain keys. The two largest of these special routines are the groups of subroutines which evaluate the conduction transfer functions and the window optics.

The loads calculator is divided into three sections. The first section reads the file created by the IP and fills the LC arrays. It checks for sufficient array space and performs some checks which require that all data for the problem description be present in the arrays. The second section uses the geometric and optical descriptions of the building surfaces to compute solar gain factors for various periods of the year. The third section does the actual heat balances necessary to compute the multi-room loads on a hour-by-hour basis.

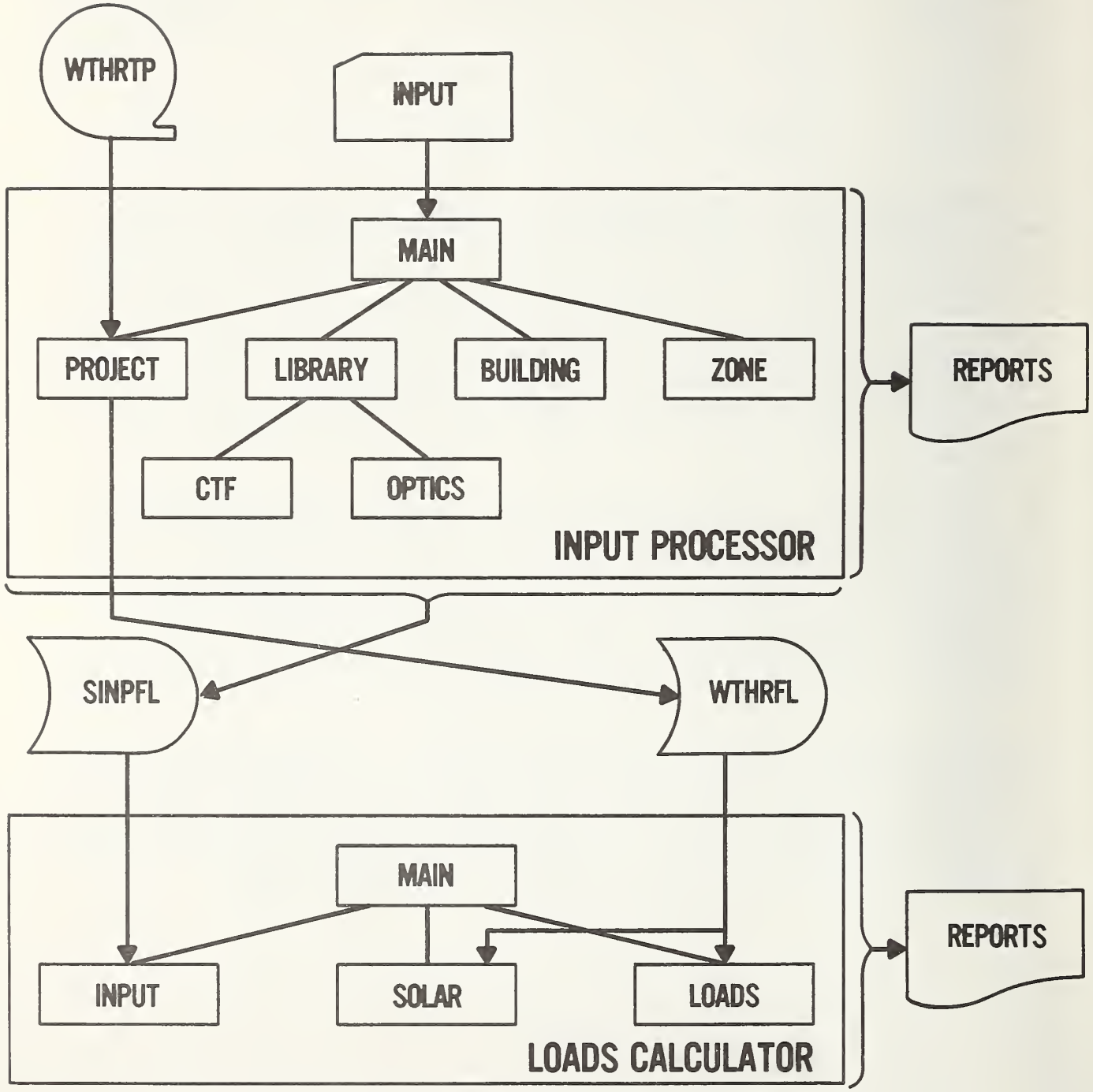


Figure A-1. MRLP structure

APPENDIX B: SIMULATION INPUT

It is intended that the MRLP input deck be an on-line file which is created and modified by a text editing system. It can also be a deck of punched cards. There is a simple, consistent input structure. The input is based on a keyword system (keyword = value) to produce a free-format, self-descriptive input language. In some ways it is similar to NAMELIST input which is a feature of some versions of FORTRAN. The keyword system is organized in a logical heirarchy which groups related concepts and data. Defaulting is used extensively. This applies to individual values and to groups of values representing entire elements of building operation or description. Some groups of often used data can be named and then used many times by referring to the name.

The input deck for the test case (appendix C) demonstrates the features of the input language. On the first page of the townhouse input deck nine lines below "LIBRARY" is the line:

```
MATL(NAME=GYP/DESC='GYPSUM WALLBOARD'/K=.42/D=100./CP=.2)
```

This line of input describes the conductivity (K=.42), density (D=100.), and specific heat (CP=.2) of a gypsum wallboard, and gives this material the name GYP. Other properties of this material which are not mentioned, such as its roughness, solar absorptance, and thermal emittance, are given default values by the input processor. Twelve lines further down is the input:

```
CONS(NAME=PTN-S/DESC='PARTITION - STUD AREA'/
    MATL=.0417,GYP,.292,WD-S,.0417, GYP)
```

This describes the partition walls at the studs and gives this construct the name PTN-S. It consists of two .0417 ft (.5 in) thick layers of the already defined GYP (wallboard) with a 0.292 ft (3.5 in) thick layer of WD-S (softwood) between them. This construct is then used in the input at the bottom of the second page:

```
SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=3.5,8.5)
```

This line is describing the stud area of the partition along the east side of the first zone of the townhouse. IN means this is an interior rather than envelope surface. This will determine the type of surface heat balance performed. OP means it is opaque instead of transparent and determines which algorithm is used to model the effects of solar energy and other short-wavelength thermal radiations on the surface. BS means it is a base surface. That is, its location and orientation are not based on another surface. This surface faces east (AZM=90) and is 3.5 ft wide by 8.5 ft high (SIZE=3.5,8.5). This width is the combined width of all studs in the wall.

APPENDIX C: TOWNHOUSE INPUT DECK

```
PROJECT [
  RC(XREF/DEM/UIN=ENGLISH/UOUT=METRIC/
     DESC='4 ZONE HASTINGS TOWN HOUSE PLUS ATTIC')
  RPT(RNOS = 8, 21)
  LOC(DESC='COLUMBIA, MO.'/LATD=38.9/LONG=92.3/TZ=6)
  GRND(GRT=56,55,56,59,61,65,68,70,69,66,62,59)
  DDY(DESC='COLUMBIA WINTER'/HIGH=26/LOW=6/WB=20/DATE=21JAN/PRES=405/
      WS=1320/DIR=0/CLR=1./SAT)
  ]
LIBRARY  [
  LIB(NMATL=32/NCONS=32)
  MATL(NAME=C-HW/DESC='CONCRETE - SAND & GRAVEL'/K=1.104/D=140./CP=.2)
  MATL(NAME=R5/DESC='R5 POLYSTYRENE'/R=5.)
  MATL(NAME=B1/DESC='AIRSPACE RESISTANCE'/R=.91)
  MATL(NAME=R11/DESC='R11 INSULATION'/R=11.)
  MATL(NAME=R19/DESC='R19 INSULATION'/R=19.)
  MATL(NAME=WD-S/DESC='SOFTWOOD'/K=.0675/D=32./CP=.33)
  MATL(NAME=WD-H/DESC='HARDWOOD'/K=.092/D=45./CP=.3)
  MATL(NAME=GYP/DESC='GYPSUM WALLBOARD'/K=.42/D=100./CP=.2)
  MATL(NAME=SHTH/DESC='INTERMEDIATE DENSITY BUILDING BOARD SHEATHING'/
       K=.034/D=22./CP=.31)
  MATL(NAME=AL/DESC='ALUMINUM SIDING'/K=128./D=171./CP=.214)
  MATL(NAME=CPT/DESC='CARPET & FIBROUS PAD'/R=2.08)
  MATL(NAME=E4/DESC='CEILING AIRSPACE'/R=1.0)
  MATL(NAME=SPDS/DESC='SINGLE PANE, DOUBLE STRENGTH GLASS'/
       GLASS/R=.0236/TRNS=.87)
  MATL(NAME=DIRT/K=.1/D=65./A=.70)
  MATL(NAME=ASH/DESC='ASPHALT SHINGLES'/K=18.16/D=70/CP=.3)
  CONS(NAME=PTN-A/DESC='PARTITION - AIR SPACE AREA'/
       MATL=.0417,GYP, 0,B1, .0417,GYP)
  CONS(NAME=PTN-S/DESC='PARTITION - STUD AREA'/
       MATL=.0417,GYP, .292,WD-S, .0417,GYP)
  CONS(NAME=WL-I/DESC='EXTERIOR WALL - INSULATION AREA'/
       MATL=.0052,AL, .0417,SHTH, 0,R11, .0417,GYP)
  CONS(NAME=WL-S/DESC='EXTERIOR WALL - STUD AREA'/
       MATL=.0052,AL, .0417,SHTH, .292,WD-S, .0417,GYP)
  CONS(NAME=WDW/DESC='SINGLE PANE WINDOW OR GLASS DOOR'/MATL=0,SPDS)
  CONS(NAME=CLG2-I/DESC='CEILING UNDER ATTIC - INSULATION AREA'/
       MATL=0,R19, .0417,GYP)
  CONS(NAME=CLG2-T/DESC='CEILING UNDER ATTIC - TRUSS AREA'/
       MATL=.458,WD-S, .0417,GYP)
  CONS(NAME=FLR3-I/DESC='ATTIC FLOOR - INSULATION AREA'/
       MATL=.0417,GYP, 0,R19)
  CONS(NAME=FLR3-T/DESC='ATTIC FLOOR - TRUSS AREA'/
       MATL=.0417,GYP, .458,WD-S)
  CONS(NAME=CLG1-A/DESC='FIRST FLOOR CEILING - AIR SPACE AREA'/
       MATL=0,CPT, .0625,WD-S, 0,E4, .0417,GYP)
  CONS(NAME=CLG1-I/DESC='FIRST FLOOR CEILING - INSULATED AREA'/
       MATL=.0625,WD-S, 0,R11, 0,B1, .0417,GYP)
  CONS(NAME=CLG1-T/DESC='FIRST FLOOR CEILING - TRUSS AREA'/
       MATL=0,CPT, .0625,WD-S, .792,WD-S, .0417,GYP)
```

```
  CONS(NAME=FLR2-A/DESC='SECOND FLOOR FLOOR - AIR SPACE AREA'/
       MATL=.0417,GYP, 0,E4, .0625,WD-S, 0,CPT)
  CONS(NAME=FLR2-T/DESC='SECOND FLOOR FLOOR - TRUSS AREA'/
       MATL=.0417,GYP, .792,WD-S, .0625,WD-S, 0,CPT)
  CONS(NAME=FLR2-I/DESC='SECOND FLOOR FLOOR - INSULATION AREA'/
       MATL=.03125,WD-S, 0,B1, 0,R11, .0625,WD-S, 0,CPT)
  CONS(NAME=PTN-I/DESC='PARTITION - INSULATION AREA'/
       MATL=.0417,GYP, 0,R11, .0417,GYP)
  CONS(NAME=ROOF-A/DESC='ROOF - BETWEEN TRUSSES'/
       MATL=.0104,ASH, .0417,WD-S)
  CONS(NAME=ROOF-T/DESC='ROOF - AT TRUSSES'/
       MATL=.0104,ASH, .04176,WD-S, .292,WD-S)
  CONS(NAME=SLAB/DESC='SLAB FLOOR'/
       MATL=.5,DIRT, 0,R5, .333,C-HW, 0,CPT)
  CONS(NAME=DOOR/DESC='FRONT ENTRY'/MATL=.146,WD-H)
  DS(NAME=LBWD/DESC='LIGHTS - BEDROOMS - WINTER - WEEKDAY'/
     FFC=6*0,2*.5,9*0,6*.5,0)
  DS(NAME=LKWD/DESC='LIGHTS - KITCHEN - WINTER - WEEKDAY'/
     FFC=6*0,2*.8,9*0,2*.7,4*.4,0)
  DS(NAME=LLWD/DESC='LIGHTS - LIVING ROOM - WINTER - WEEKDAY'/
     FFC=6*0,2*.2,9*0,2*.3,3*.7,.3,0)
  DS(NAME=CONST/DESC='CONSTANT'/FFC=24*1)
  DS(NAME=EKWD/DESC='EQUIPMENT - KITCHEN - WINTER - WEEKDAY'/
     FFC=6*0,2*.5,9*0,1,2*.2,4*0)
  WS(NAME=LBW/DESC='LIGHTS - BEDROOMS - WINTER'/WD=LBWD)
  WS(NAME=LKW/DESC='LIGHTS - KITCHEN - WINTER'/WD=LKWD)
  WS(NAME=LLW/DESC='LIGHTS - LIVING RM - WINTER'/WD=LLWD)
  WS(NAME=CONST/DESC='CONSTANT'/ALL=CONST)
  WS(NAME=EKW/DESC='EQUIPMENT - KITCHEN - WINTER'/WD=EKWD)
  CPFL(NAME=HT/DESC='NORMAL HEATING'/TMP=70,70/CAP=1,0)
  CPFL(NAME=SB/DESC='SETBACK HEATING'/TMP=65,65/CAP=1,0)
  CPFL(NAME=CL/DESC='COOLING'/TMP=65,65,78,78/CAP=1,0,0,-1)
  CDS(NAME=WD/DESC='WINTER - WEEKDAY'/CPFL=6*SB,2*HT,9*SB,6*HT,SB)
  CWS(NAME=WINTER/DESC='WINTER'/WD=WD)
  ]
BUILDING [
  SIM(SLDS=2/HTB=1/FLOW=.0001,.0001,80,.9/CNVG=.01,.001,.1,12)
$                                       NORTH SIDE SHADING
  DSS(AZM=90/ORG=.29,34,0/SIZE=2,17.17)
  DSS(AZM=270/ORG=19.71,36,0/SIZE=2,17.17)
$                                       SOUTH SIDE SHADING
  DSS(AZM=270/ORG=20,2,0/SIZE=17.2,2)
  ]
ZONE [
$                                       FIRST FLOOR + STAIRWELL
  GEOM(NAME=FLR1/Z=.67/CLHT=8.5)
$                                       WEST PARTITION + STAIRWELL - 311.
  SRF(CONS=PTN-A/IN/OP/BS/AZM=270/SIZE=32.62,8.5)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=270/SIZE=4.00,8.5)
$                                       EAST PARTITION - 272.
  SRF(CONS=PTN-A/IN/OP/BS/AZM=90/SIZE=28.5,8.5)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=3.5,8.5)
```

```
$                                       INTERNAL PARTITIONS - 167.4,24.9,80.6
  SRF(CONS=PTN-A/IN/OP/BS/AZM=180/SIZE=19.44,7.67/ZONE=MBDRM)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=180/SIZE=2.39,7.67/ZONE=MBDRM)
    AFS(AREA=.5/ZS=12.5)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=90/SIZE=2.9,7.67/ZONE=BDRM2)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=.35,7.67/ZONE=BDRM2)
    AFS(AREA=.5/ZS=12.5)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=0/SIZE=9.36,7.67/ZONE=BDRM3)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=0/SIZE=1.15,7.67/ZONE=BDRM3)
    AFS(AREA=.5/ZS=12.5)
$                                       INTERNAL MASS
  MASS(CONS=PTN-A/AREA=795)
  MASS(CONS=PTN-S/AREA=98)
$                                       NORTH EXTERIOR WALL - 165.1
  SRF(CONS=WL-S/EX/OP/BS/AZM=0/SIZE=2.0,8.5/ORG=2.29,34,.67)
    AFS(AREA=.050)
    AFS(AREA=.047/ZS=.1)
  SRF(CONS=WL-I/EX/OP/BS/AZM=0/SIZE=17.42,8.5/ORG=19.71,34,.67)
$                                           GLASS DOOR
    SRF(CONS=WDW/EX/TR/SS/SIZE=5.73,6.72/ORG=2.24,.47,-.17)
$                                           WINDOW
    SRF(CONS=WDW/EX/TR/SS/SIZE=4.98,3.83/ORG=12.2,3.5,-.17)
$                                       SOUTH EXTERIOR WALL - 222.9
  SRF(CONS=PTN-I/EX/OP/BS/SIZE=5.3,8.5)
    OSC(TZP=.3/TAP=.7)
  SRF(CONS=WL-I/EX/OP/BS/AZM=180/SIZE=6.67,8/ORG=3.75,3.67,.67)
    SRF(CONS=DOOR/EX/OP/SS/SIZE=3.1,6.97/ORG=0,.1,0)
  SRF(CONS=WL-S/EX/OP/BS/AZM=180/SIZE=7,8/ORG=10.42,0,.67)
    SRF(CONS=WDW/EX/TR/SS/SIZE=5.73,6.72/ORG=.63,.33,-.17)
  SRF(CONS=WL-I/EX/OP/BS/AZM=270/SIZE=2.77,8/ORG=10.42,2.77,.67)
  SRF(CONS=WL-S/EX/OP/BS/AZM=270/SIZE=.9,8/ORG=10.42,3.67,.67)
  SRF(CONS=WL-I/EX/OP/BS/AZM=90/SIZE=2,8.5/ORG=17.4,0,.67)
  SRF(CONS=WL-I/EX/OP/BS/AZM=180/TILT=90/SIZE=2.6,8.5/ORG=17.4,2,.67)
    AFS(AREA=.060)
    AFS(AREA=.058/ZS=.1)
$                                       FLOOR
  SRF(CONS=SLAB/EX/OP/BS/AZM=180/TILT=180/SIZE=20,31.6/ORG=0,34,.67)
    OSC(TGP=1)
$                                       CEILINGS - 129.1, 216.4, 129., 104.3
  SRF(CONS=CLG2-I/IN/OP/BS/TILT=0/SIZE=11.97,10/ZONE=ATTIC)
  SRF(CONS=CLG2-T/IN/OP/BS/TILT=0/SIZE=.94,10/ZONE=ATTIC)
    AFS(AREA=.049/ZS=16.5)
  SRF(CONS=CLG1-A/IN/OP/BS/TILT=0/SIZE=19.27,10/ZONE=MBDRM)
  SRF(CONS=CLG1-T/IN/OP/BS/TILT=0/SIZE=2.37,10/ZONE=MBDRM)
    AFS(AREA=.167/ZS=8.5)
  SRF(CONS=CLG1-A/IN/OP/BS/TILT=0/SIZE=11.49,10/ZONE=BDRM2)
  SRF(CONS=CLG1-T/IN/OP/BS/TILT=0/SIZE=1.41,10/ZONE=BDRM2)
    AFS(AREA=.065/ZS=8.5)
  SRF(CONS=CLG1-A/IN/OP/BS/TILT=0/SIZE=9.29,10/ZONE=BDRM3)
  SRF(CONS=CLG1-T/IN/OP/BS/TILT=0/SIZE=1.14,10/ZONE=BDRM3)
    AFS(AREA=.080/ZS=8.5)
  SRF(CONS=CLG1-I/EX/OP/BS/TILT=0/AZM=0/SIZE=7,2/ORG=10.4,2,8)
```

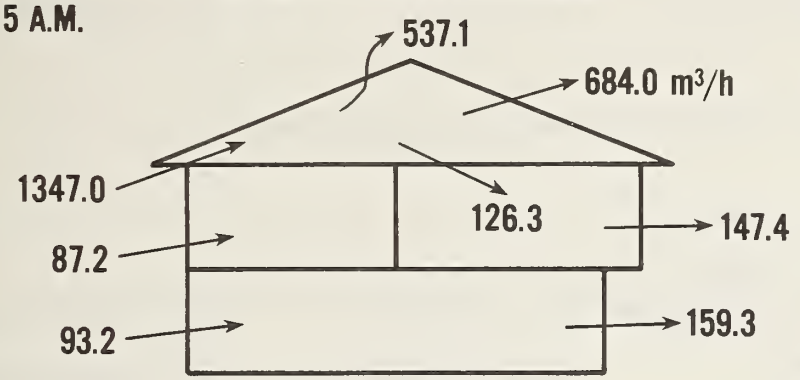
```
$                                          SCHEDULES
  LIT(WS=LKW/CAP=.7)
  LIT(WS=LLW/CAP=1.2/RAD=.8/VIS=.1)
  EQP(WS=EKW/CAP=5.9)
  EQP(WS=CONST/CAP=1.5)
  CTRL(CWS=WINTER/)
  ]
ZONE [
$                                          MASTER BEDROOM
  GEOM(NAME=MBDRM/Z=9.17/CLHT=8)
$                                          PARTITIONS - 76.5, 137.4, 167.4, 41.4
  SRF(CONS=PTN-A/IN/OP/BS/AZM=180/SIZE=8.88,7.67)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=270/SIZE=1.09,7.67)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=90/SIZE=15.96,7.67)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=1.96,7.67)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=0/SIZE=19.44,7.67/ZONE=FLR1)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=0/SIZE=2.39,7.67/ZONE=FLR1)
    AFS(AREA=.5/ZS=4.)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=0/SIZE=4.8,7.67/ZONE=BDRM2)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=0/SIZE=.6,7.67/ZONE=BDRM2)
    AFS(AREA=.019/ZS=4.)
  SRF(CONS=PTN-A/IN/OP/BS/SIZE=9,8)
$                                          SOUTH WALL - 189.5
  SRF(CONS=WL-I/EX/OP/BS/AZM=270/SIZE=1.78,8/ORG=0,2,0)
  SRF(CONS=WL-S/EX/OP/BS/AZM=270/SIZE=.22,8/ORG=0,1.78,0)
    SHD(LFIN/SIZE=8,10/ORG=0,0,0)
  SRF(CONS=WL-I/EX/OP/BS/AZM=180/SIZE=9.6,8/ORG=0,0,0)
  SRF(CONS=WL-S/EX/OP/BS/AZM=180/SIZE=1.2,8/ORG=9.6,0,0)
  SRF(CONS=WL-I/EX/OP/BS/AZM=90/SIZE=1.78,8/ORG=10.75,0,0)
  SRF(CONS=WL-S/EX/OP/BS/AZM=90/SIZE=.22,8/ORG=10.75,1.78,0)
  SRF(CONS=WL-I/EX/OP/BS/AZM=180/SIZE=7.92,8/ORG=10.75,2,0)
    SRF(CONS=WDW/EX/TR/SS/SIZE=5.73,6.72/ORG=0,.25,-.17)
  SRF(CONS=WL-S/EX/OP/BS/AZM=180/SIZE=.97,8/ORG=18.67,2,0)
    AFS(AREA=.055)
    AFS(AREA=.054/ZS=8.)
$                                          FLOOR
  SRF(CONS=FLR2-I/EX/OP/BS/AZM=180/TILT=180/SIZE=3.27,10.42/ORG=0,3.67,0)
  SRF(CONS=FLR2-T/EX/OP/BS/AZM=180/TILT=180/SIZE=.40,10.42/ORG=0,.40,0)
  SRF(CONS=FLR2-A/IN/OP/BS/TILT=180/SIZE=19.27,10/ZONE=FLR1)
  SRF(CONS=FLR2-T/IN/OP/BS/TILT=180/SIZE=2.37,10/ZONE=FLR1)
    AFS(AREA=.167)
$                                          CEILING - 256.7
  SRF(CONS=CLG2-I/IN/OP/BS/TILT=0/SIZE=23.8,10/ZONE=ATTIC)
  SRF(CONS=CLG2-T/IN/OP/BS/TILT=0/SIZE=1.87,10/ZONE=ATTIC)
    AFS(AREA=.096/ZS=8.)
$                                          SCHEDULES
  LIT(WS=LBW/CAP=.6/RAD=.8/VIS=.1)
  CTRL(CWS=WINTER)
  ]
ZONE [
$                                          BEDROOM #2
  GEOM(NAME=BDRM2/Z=9.17/CLHT=8)
```

```
$                                          PARTITIONS - -,41.4, -, 82.8
  SRF(CONS=PTN-A/IN/OP/BS/AZM=90/SIZE=14.16,7.67)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=1.74,7.67)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=180/SIZE=4.8,7.67/ZONE=MBDRM)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=180/SIZE=.6,7.67/ZONE=MBDRM)
    AFS(AREA=.019/ZS=4.)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=270/SIZE=2.9,7.67/ZONE=FLR1)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=270/SIZE=.35,7.67/ZONE=FLR1)
    AFS(AREA=.5/ZS=4.)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=270/SIZE=9.6,7.67/ZONE=BDRM3)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=270/SIZE=1.2,7.67/ZONE=BDRM3)
    AFS(AREA=.038/ZS=4.)
$                                          NORTH WALL - 77.7
  SRF(CONS=WL-I/EX/OP/BS/AZM=0/SIZE=8.65,8/ORG=19.72,34,0)
    SRF(CONS=WDW/EX/TR/SS/SIZE=5.0,4.17/ORG=2.35,3.5,-.17)
  SRF(CONS=WL-S/EX/OP/BS/AZM=0/SIZE=1.06,8/ORG=11.07,34,0)
    AFS(AREA=.022)
    AFS(AREA=.020/ZS=8.)
$                                          FLOOR
  SRF(CONS=FLR2-A/IN/OP/BS/TILT=180/SIZE=11.49,10/ZONE=FLR1)
  SRF(CONS=FLR2-T/IN/OP/BS/TILT=180/SIZE=1.41,10/ZONE=FLR1)
    AFS(AREA=.065)
$                                          CEILING - 192.
  SRF(CONS=CLG2-I/IN/OP/BS/TILT=0/SIZE=11.9,10/ZONE=ATTIC)
  SRF(CONS=CLG2-T/IN/OP/BS/TILT=0/SIZE=.94,10/ZONE=ATTIC)
    AFS(AREA=.048/ZS=8.)
$                                          SCHEDULES
  LIT(WS=LBW/CAP=.4/RAD=.8/VIS=.1)
  CTRL(CWS=WINTER)
  ]
ZONE [
$                                          BEDROOM #3
  GEOM(NAME=BDRM3/Z=9.17/CLHT=8)
$                                          PARTITIONS - 80.6, 82.8, 92.8
  SRF(CONS=PTN-A/IN/OP/BS/AZM=180/SIZE=9.36,7.67/ZONE=FLR1)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=180/SIZE=1.15,7.67/ZONE=FLR1)
    AFS(AREA=.5/ZS=4)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=90/SIZE=9.6,7.67/ZONE=BDRM2)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=90/SIZE=1.2,7.67/ZONE=BDRM2)
    AFS(AREA=.038/ZS=4)
  SRF(CONS=PTN-A/IN/OP/BS/AZM=270/SIZE=10.8,7.67)
  SRF(CONS=PTN-S/IN/OP/BS/AZM=270/SIZE=1.3,7.67)
$                                          NORTH WALL - 77.7
  SRF(CONS=WL-I/EX/OP/BS/AZM=0/SIZE=8.65,8/ORG=10,34,0)
    SRF(CONS=WDW/EX/TR/SS/SIZE=5.0,4.17/ORG=2.35,3.5,-.17)
  SRF(CONS=WL-S/EX/OP/BS/AZM=0/SIZE=1.06,8/ORG=1.35,34,0)
    AFS(AREA=.022)
    AFS(AREA=.020/ZS=8.)
$                                          FLOOR - 104.3
  SRF(CONS=FLR2-A/IN/OP/BS/TILT=180/SIZE=9.29,10/ZONE=FLR1)
  SRF(CONS=FLR2-T/IN/OP/BS/TILT=180/SIZE=1.14,10/ZONE=FLR1)
    AFS(AREA=.080)
```

```
$                                       CEILING - 104.3
  SRF(CONS=CLG2-I/IN/OP/BS/TILT=0/SIZE=9.67,10/ZONE=ATTIC)
  SRF(CONS=CLG2-T/IN/OP/BS/TILT=0/SIZE=.76,10/ZONE=ATTIC)
    AFS(AREA=.039/ZS=8.)
$                                       SCHEDULES
  LIT(WS=LBW/CAP=.4/RAD=.8/VIS=.1)
  CTRL(CWS=WINTER)
  ]
ZONE [
$                                       ATTIC
  GEOM(NAME=ATTIC/Z=17.17/CLHT=2.2)
$                                       ATTIC FLOOR - 129.1, 256.4, 129.,  104.3
  SRF(CONS=FLR3-I/IN/OP/BS/TILT=180/SIZE=11.97,10/ZONE=FLR1)
  SRF(CONS=FLR3-T/IN/OP/BS/TILT=180/SIZE=.94,10/ZONE=FLR1)
    AFS(AREA=.049)
  SRF(CONS=FLR3-I/IN/OP/BS/TILT=180/SIZE=23.8,10/ZONE=MBDRM)
  SRF(CONS=FLR3-T/IN/OP/BS/TILT=180/SIZE=1.87,10/ZONE=MBDRM)
    AFS(AREA=.096)
  SRF(CONS=FLR3-I/IN/OP/BS/TILT=180/SIZE=11.9,10/ZONE=BDRM2)
  SRF(CONS=FLR3-T/IN/OP/BS/TILT=180/SIZE=.94,10/ZONE=BDRM2)
    AFS(AREA=.048)
  SRF(CONS=FLR3-I/IN/OP/BS/TILT=180/SIZE=9.67,10/ZONE=BDRM3)
  SRF(CONS=FLR3-T/IN/OP/BS/TILT=180/SIZE=.76,10/ZONE=BDRM3)
    AFS(AREA=.039)
  SRF(CONS=ROOF-A/EX/OP/BS/AZM=0/TILT=180/ORG=19.71,34,0/SIZE=19.42,2)
    AFS(AREA=2./EXP=.5)
$                                       ROOF
  SRF(CONS=ROOF-A/EX/OP/BS/AZM=180/TILT=22.6/SIZE=20,18.8/ORG=0,0,0)
    AFS(AREA=.35)
  SRF(CONS=ROOF-A/EX/OP/BS/AZM=0/TILT=22.6/SIZE=20,18.8/ORG=20,34,0)
    AFS(AREA=.35)
$                                       NO SCHEDULES
  ]
```

21 JAN
5 A.M.

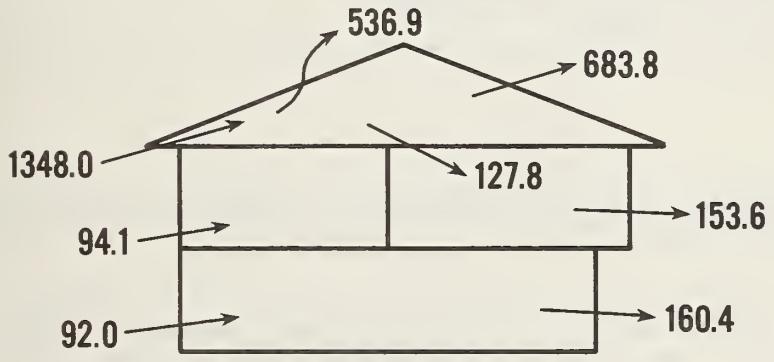
SMALL INTER-ROOM OPENINGS



1.00 ach
7.34 kWh
8.2 sec/day

CASE 7a

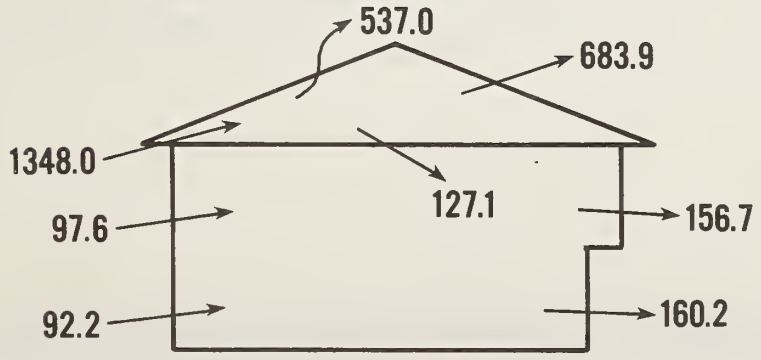
STANDARD OPENINGS



1.02 ach
7.41 kWh
11.1 sec/day

CASE 7b

SINGLE ZONE



1.03 ach
7.42 kWh
4.6 sec/day

CASE 7c

CASE 7d

AIR CHANGE METHOD:

using same ach
gives same load
3.9 sec/day

NBS-114A (REV. 2-8C)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A model is presented for computing the infiltration and air flow between rooms of a multi-room building in terms of basic principles of fluid mechanics. This model has been incorporated into a comprehensive loads-predicting computer program. Air flows, room temperatures, and heating loads for a typical townhouse under different conditions of environment and with various construction features are computed. These calculations show the feasibility of detailed multi-room air movement analysis. They also indicate that when the inter-room openings of a low-rise structure are large compared to the envelope openings, the infiltration and total load can be accurately, and more quickly, computed by assuming no resistance to air flow between rooms. This property will also allow simplified calculations for high-rise buildings with many rooms. Methods are proposed for handling more complex air flow phenomena.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

building energy analysis; computer simulation; infiltration; natural ventilation

13. AVAILABILITY

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